# ESTCP
# Cost and Performance Report

(WP-200303)


## Scale-Up, Demonstration and Validation of Environmentally Advantaged and Reliable Coatings: FP 212 Experimental Coating

**July 2008**

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ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

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| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
|---|---|



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 7-30-2008 | Cost & Performance Report | 03/2003 – 12/2007 |

**4. TITLE AND SUBTITLE**

FP 212 Cost and Performance Report

**5a. CONTRACT NUMBER**

WP – 0303

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

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**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

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**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

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1801 Tenth Street, Bldg. B, Suite 2
Wright-Patterson AFB, OH 45433

**10. SPONSOR/MONITOR'S ACRONYM(S)**

ASC/ENVV

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Distribution Statement "A" applies. Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

This Environmental Security Technology Certification Program (ESTCP) project focused on the demonstration and validation of the low Volatile Organic Compound/Hazardous Air Pollutant (VOC/HAP), rapid deposition, quick cure aerospace coating, FP 212. Testing and demonstration/validation activities were performed at Lockheed Martin Aeronautics Company (LM Aero) facilities within Air Force Plant 4 (AFP 4), Ft. Worth, TX. The results from this effort provided stakeholders with side-by-side comparisons of FP 212 and a baseline coating in terms of durability, failure mode, and application properties. FP 212 demonstrated environmental, application, and durability advantages relative to the current baseline coating, which will result in significant life-cycle environmental and economic savings for the weapons system of interest.

**15. SUBJECT TERMS**

Aerospace Coatings, Low VOC, Paint Emissions, Rapid Deposition, Quick Cure, Durable

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)* |
|---|---|---|---|---|---|
| U | U | U | UU | **50** | Roddy Keish / 937-255-3541 |

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Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AFP | Air Force Plant |
| AFRL/MLSC | Air Force Research Laboratory, Materials and Manufacturing Directorate, Acquisition Systems Support Branch |
| AMS | SAE Aerospace Material Specification |
| ASC/ENVV | Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch |
| ASTM | American Society for Testing and Materials |
| CAA | Clean Air Act |
| CI | Confidence Interval |
| DoD | Department of Defense |
| ECAM | Environmental Cost Analysis Methodology |
| EPA | Environmental Protection Agency |
| ESTCP | Environmental Security Technology Certification Program |
| FED-STD | Federal Standard |
| FSE | Field Service Evaluation |
| g/L | Grams per Liter |
| GOCO | Government-Owned, Contractor-Operated |
| HAP | Hazardous Air Pollutant |
| IRR | Internal Rate of Return |
| LCC | Life-Cycle Cost |
| LM Aero | Lockheed Martin Aeronautics Company |
| MEK | Methyl Ethyl Ketone |
| MIBK | Methyl Isobutyl Ketone |
| MPK | Methyl Propyl Ketone |
| Mil | 0.001 inches |
| NDCEE | National Defense Center for Environmental Excellence |
| NESHAP | National Emission Standards for Hazardous Air Pollutants |
| NPV | Net Present Value |
| O&M | Operations and Maintenance |
| OEM | Original Equipment Manufacturer |
| OMB | Office of Management and Budget |
| OO-ALC | Ogden Air Logistics Center, Hill AFB, UT |

| | |
|---|---|
| PDM | Programmed Depot Maintenance |
| PPE | Personal Protective Equipment |
| QPL | Qualified Products List |
| RH | Relative Humidity |
| SAE | Society of Automotive Engineers |
| SAIC | Science Applications International Corporation |
| SPO | Systems Program Office |
| TIM | Technical Interchange Meeting |
| VOC | Volatile Organic Compound |
| WPAFB | Wright-Patterson Air Force Base |
| WS | Weapon System |

# ACKNOWLEDGEMENTS

This Cost and Performance Report was prepared by Science Applications International Corporation (SAIC) employees Lucas Reyher and Thomas Ferrill under the guidance of James Byron at the SAIC, Dayton, OH facility. This report was completed under Project Number WP-0303 for the Environmental Security Technology Certification Program (ESTCP). Special acknowledgements go to all Lockheed Martin Aeronautics Company (LM Aero) personnel who supported this program. Individuals at LM Aero who were key to this program's success include Randall Reed, Greg Flusche, Mark Taylor, Kelly Choban, and Larry Burton. Within the Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch (ASC/ENVV), gratitude is given to Capt Lowell Usrey, Frank Ivancic, Frank Brown, and Roddy Keish for providing program management and coordination between all interested parties. Personnel from the Air Force Research Laboratory (AFRL), WPAFB, OH, provided excellent technical oversight and recommendations throughout this program. Special thanks are given to ESTCP for supporting this program and for promoting good stewardship of the environment through the demonstration and validation of innovative environmental technologies.

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# EXECUTIVE SUMMARY

## SCOPE OF ESTCP PROJECT WP-0303

The overall scope of this ESTCP Project (WP-0303) focused on testing and demonstrating two low Volatile Organic Compound (VOC), rapid deposition, quick cure aerospace coatings. These coatings, FP 60-2 and FP 212, were formulated to meet the material property requirements of separate Weapon Systems (WS). At the start of this ESTCP program, FP 60-2 and FP 212 were in different stages of development and use and had different qualification and demonstration requirements for the two WS platforms of interest, which necessitated two separate ESTCP Demonstrations Plans, one for FP 60-2 and one for FP 212. Separate ESTCP Cost and Performance Reports were written to report on the results of completing the two Demonstration Plans. This report addresses the Cost and Performance of FP 212. The ESTCP Cost and Performance Report for FP 60-2 is available from ESTCP.

## BACKGROUND

Conventional aerospace coatings are typically applied as paints to varying thicknesses, depending on the specific application. Applying these coatings to desired thicknesses often requires significant labor hours for application, requiring multiple application passes of only a few mils (mil = 0.001 inch) per pass while allowing 5 to 10 minutes between passes for solvent flash. Typical aerospace coating stack-up applications require several hours and multiple working shifts to complete, as well as long cure times which often create bottlenecks in Department of Defense (DoD) production and Programmed Depot Maintenance (PDM) processes and result in logistical issues during field repairs. These coatings often contain significant quantities of VOCs and Hazardous Air Pollutants (HAPs) such as Methyl Ethyl Ketone (MEK), Methyl Isobutyl Ketone (MIBK), toluene, or xylene. The continued use of these high-VOC/Hazardous Air Pollutant (HAP) processes presents significant logistical and safety issues, as well as relatively long manufacturing/repair flow times. Use of low VOC, rapid deposition, quick cure aerospace coatings has the potential beneficial impacts of improving worker safety, reducing VOC/HAP emissions, and decreasing the flow times of manufacturing and repair processes.

This program demonstrated the performance of a low VOC, rapid deposition, quick cure aerospace coating, designated FP 212. The VOC content of FP 212 is 40 grams per liter (g/L), which is a 90 percent reduction in VOC content relative to the baseline coating, with a VOC content of 420 g/L. The relatively low VOC content of FP 212 was achieved by using Oxsol 100® as the primary solvent. According to Environmental Protection Agency (EPA) guidelines, Oxsol 100® is not considered a VOC since it does not react with atmospheric compounds to form ozone in the lower atmosphere.

Lab-scale studies were performed on FP 212 to assess durability and failure mode properties. The full-scale capabilities of FP 212 were demonstrated and validated during full-scale application studies.

## OBJECTIVES OF THE DEMONSTRATION

The objectives of this demonstration were to compare the durability, failure mode, and full-scale application properties of FP 212 to those of the baseline coating of the WS of interest and to demonstrate environmental and economic advantages of FP 212 relative to the baseline material. Lab-scale testing was carried out by Lockheed Martin Aeronautics Company (LM Aero) at Air Force Plant 4 (AFP 4), Ft. Worth, TX. Full-scale application studies performed at AFP 4 using full-scale manual spray equipment and a full-scale structure from the WS of interest provided side-by-side comparisons of the application properties of FP 212 and the baseline material and confirmed environmental and economic advantages of FP 212 relative to the baseline material.

## REGULATORY DRIVERS

Title V of the Clean Air Act (CAA) was the primary regulatory driver for this project. Aerospace coating stack-ups often contribute significantly to a facility's overall emissions, which are subject to state, local and site restrictions on total VOC emissions and are regulated under the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations.

## DEMONSTRATION RESULTS

The performance of FP 212 during this program was acceptable and demonstrated environmental and economic advantages relative to the baseline material. The formulation of FP 212 results in a 90 percent reduction in VOC content relative to the baseline material. As a result, VOC emissions during production and repair processes will be significantly reduced on a per-aircraft basis. FP 212 exhibited smoother surface finish and could be sprayed to tighter thickness tolerances than the baseline material, which will lead to decreases in labor hours required for sanding on a per-aircraft basis to achieve smooth surface finish and desired dry coating thickness.

During this program, the durability of FP 212 in a simulated maritime environment was observed to be significantly superior to the durability of the baseline material in the same environment. This was an unexpected advantage of FP 212 relative to the baseline material. The advantage of increased durability of FP 212 relative to the baseline material demonstrates the superior durability of the resin that is used in the formulation of FP 212 (002 resin) compared to the durability of the resin that is used in the formulation of the baseline material (001 resin). The WS of interest will not realize significant environmental nor economic savings due to the increased durability of the 002 resin in maritime environments compared to the durability of the 001 resin in the same environment since only a small number of aircraft of the WS of interest operate continuously in maritime environments. However, as discussed in the FP 60-2 Cost and Performance Report for FP 60-2, which is available from ESTCP, FP 60-2, like FP 212, is formulated with the 002 resin and the baseline material that FP 60-2 will replace (FP 60) is formulated with the 001 resin, like the baseline material that FP 212 will replace. Since the resin of a coating is largely responsible for its durability, the results of FP 212 and baseline material durability testing are relevant for FP 60-2 and FP 60. Unlike the FP 212-targeted WS of interest, the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments is expected to result in reductions in the Life-Cycle Costs (LCC) and life-cycle VOC emissions for the FP 60-2-targeted WS of interest since many of the FP 60-2-targeted WS of interest operate continuously in maritime environments.

As a result of the superior durability of the 002 resin in maritime environments, the frequency of repairs and level of effort to make repairs, including labor hours and material usage, will be significantly decreased for those aircraft operating continuously in maritime environments. Fewer repairs will also result in fewer VOC emissions and decreased downtime during the lifetime of the WS of interest.

The advantages of FP 212 relative to the baseline material are projected to result annual VOC emissions reductions and cost savings. The 90 percent reduction in VOC content of FP 212 relative to the baseline material will result in life-cycle reductions in VOC and HAP emissions. It is estimated that life-cycle VOC and HAP emissions of the WS of interest will be reduced by 11,131 pounds and 12,938 pounds, respectively, by replacing the baseline material with FP 212 in production processes. The present value of the expected annual savings by replacing the baseline material with FP 212 is \$129K, due to application advantages that FP 212 has relative to the baseline material. The present value of the costs associated with the testing and demonstration of FP 212 is \$530K, which results in a Net Present Value (NPV) of -\$401K for the FP 212 portion of ESTCP Project WP-0303. However, as reported in the FP 60-2 Cost and Performance Report, the present value of the expected annual savings by replacing FP 60 with FP 60-2 are much higher than the cost for testing and demonstrating FP 60-2, which leads to an extremely attractive (positive) NPV for the FP 60-2 portion of ESTCP Project WP-0303. When the economic performance of the overall ESTCP Project WP-0303 is considered by evaluating the combined economic results of the FP 212 and FP 60-2 portions of this project, the NPV is \$47 million, the payback period is less than one year on funding contributions from ESTCP and DoD as a whole, and the Internal Rate of Return (IRR) is 37.9% and 30.9% for ESTCP and DoD, respectively.

Additionally, as a result of this program, a few other materials that are formulated with the same resin as FP 212 (002 resin) have been transitioned to the WS of interest to replace baseline materials other than the one tested during this project that are formulated with the 001 resin. When the superior durability of the 002 resin relative to the 001 resin in maritime environments became apparent, LM Aero and SPO managers made the decision to qualify and transition additional 002 resin-based materials other than FP 212 to replace additional baseline coatings formulated with the 001 resin other than the baseline material tested during this project that were currently being applied to the WS of interest. If these additional 002 resin-based materials have environmental and economic advantages relative to the 001 resin-based materials that they will replace, the environmental and economic benefits resulting from this program as summarized in this report are likely conservative.

The testing and qualification of the additional 002 resin-based coatings other than FP 212 were performed under a separate Air Force program that ran parallel to this program. It was outside the scope of this ESTCP program to evaluate any coating other than FP 212 since it was not known until near the end of this program that the 002 resin would revolutionize the coating stack-up of the WS of interest.

## STAKEHOLDER/END-USER ISSUES

In order for FP 212 to replace the baseline material in production processes, LM Aero and SPO engineers required that FP 212 show acceptable durability in a simulated maritime environment and high airflow environment and show environmental and economic advantages relative to the baseline material. In addition to displaying acceptable durability in a simulated maritime environment and during airflow testing, FP 212 demonstrated environmental and economic advantages relative to the baseline material. These results have lead LM Aero and the relevant SPO to make the decision to transition FP 212 to the WS platform.

# 1.0 TECHNOLOGY DESCRIPTION

## 1.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

At the time this ESTCP program began, the baseline material was characterized by low build rate (mils/pass), long application time (application time required to build up to desired thickness), and long cure time. This baseline material is referred to hereafter as the initial baseline material. Mid way through this ESTCP program, improvements were made by the material supplier of the initial baseline material to the solvents of the initial baseline material, producing a modified baseline material, referred to hereafter as the improved baseline material. The material supplier replaced Methyl Isobutyl Ketone (MIBK) used in the formulation of the initial baseline material with Methyl Propyl Ketone (MPK) to form the improved baseline material. Both solvents are considered Volatile Organic Compounds (VOCs) by the Environmental Protection Agency (EPA) since they react with compounds in the lower atmosphere to form ozone, a known pollutant. As are result, the VOC contents of the initial baseline material and modified baseline material are the same (420 g/L). However, the change in solvents lead to increased build rate, decreased application time, and decreased cure time of the improved baseline material relative to the initial baseline material.

This program focused on improving upon the environmental and application performance of the baseline material, which, when this program began, was the initial baseline material. The proposed technology that was tested as a replacement for the baseline material was a low VOC, quick cure, rapid deposition coating designated FP 212. The initial baseline material, improved baseline material, and FP 212 were all formulated and supplied by the same material supplier. This section will describe the key design criteria used in the formulation of FP 212 and a chronological summary of the development of this coating. Key design criteria considered during the formulation of FP 212 were VOC content and application time. The goals were to decrease the VOC content relative to the initial baseline coating and to decrease the time needed to build up to desired thickness and to reach full-cure, relative to the initial baseline coating. The expected environmental and economic benefits of FP 212 that were reported in the FP 212 Demonstration Plan for ESTCP, were relative to the performance of the initial baseline material, not the improved baseline material. However, the improved baseline material, which replaced the initial baseline material mid-way through this ESTCP program, was used in the full-scale side-by-side comparison to FP 212. This full-scale side-by-side comparison generated the data that was used to complete the required financial metric calculations for this program. Throughout this report, these important points are reiterated when necessary since they impacted the benefits that FP 212 demonstrated relative to the baseline material; as results will show, the actual benefits of FP 212 relative to the improved baseline material were not as good as the benefits that FP 212 was expected to have relative to the initial baseline material.

To address lowering the VOC content, the FP 212 material supplier used solvents that are exempt by EPA standards. VOCs are defined as compounds that react with other compounds in the atmosphere to form ozone. Examples of VOCs include xylene, toluene, and Methyl Ethyl Ketone (MEK). Exempt solvents are ones that do not readily react with other atmospheric compounds to form ozone and are therefore not considered VOCs by EPA standards. Examples of exempt solvents include Oxsol 100® and acetone. The primary solvent used in the formulation of FP 212 is Oxsol 100®, which is an exempt solvent, but there are other solvents used in the formulation of FP 212 that are not exempt and result in a VOC content of 40 g/L for FP 212 compared to a VOC content of 420 g/L for the initial and improved baseline materials.

In addition to using different solvents in the formulation of FP 212 relative to the initial and improved baseline materials, the material supplier used a different resin in the formulation of FP 212. The initial and improved baseline materials were formulated with the supplier-designated 001 resin. FP 212 was formulated with the supplier-designated 002 resin. The resin used in the formulation of FP 212 was selected in order to attempt to improve upon the application properties of the initial baseline material such as the build rate (mils/pass), application time, and cure time.

Table 1 provides a summary of the different versions of the baseline material and FP 212

**Table 1. Summary of Different Versions of the Baseline Material and FP 212**

| | **Baseline Material*** | | **FP 212*, **** | |
|---|---|---|---|---|
| | **Initial** | **Improved** | **Initial** | **Improved** |
| VOC Content (g/L) | 420 | 420 | 150 | 40 |
| Resin | 001 | 001 | 002 | 002 |
| Primary Solvent | MIBK | MPK | Oxsol 100® | Oxsol 100® |
| Relevant Notes | • Estimates of FP 212 benefits were relative to initial baseline material<br>• Characterized by relatively low build rate, long application time, long cure time | • Replaced initial baseline material mid-way through ESTCP program<br>• Higher build rate, shorter application time, shorter cure time than initial baseline material | • Developed and tested a few years prior to the start of this ESTCP program for qualification to the material performance specification of a WS other than the one targeted during this program | • Tested during this ESTCP program<br>• VOC content was decreased just prior to the start of this ESTCP program<br>• Material testing was performed per the material performance specification of the WS of interest shortly after this ESTCP program began under a separate Air Force-funded program |

*All versions of the baseline material and FP 212 are supplied by the same material supplier

**All references to FP 212 in this report refer to the improved version unless otherwise specified

The chronology of development of FP 212 began in the fall of 1999. A program was initiated out of the Air Force Research Laboratory, Materials and Manufacturing Directorate, Acquisition Systems Support Branch (AFRL/MLSC) at Wright-Patterson Air Force Base (WPAFB), OH to develop aerospace coatings characterized by low VOC content and decreased overall application time relative to existing baseline aerospace coatings. The AFRL program ended with the successful development of two coatings that met all AFRL program goals, one of which was FP 212, which had a VOC content of 150 g/L. Prior to the start of this ESTCP program, Lockheed Martin Aeronautics Company (LM Aero) worked with the FP 212 material supplier under a separate Air Force-funded program to decrease the VOC content of FP 212 to 40 g/L, which is the

version of FP 212 that was used in this ESTCP program. All references to FP 212 in this report refer to the 40 g/L version, unless otherwise specified.

## 1.2 PROCESS DESCRIPTION

FP 212 was designed as a drop-in replacement for both the initial and improved baseline coatings since both of these coatings are admixed materials and can be applied with conventional manual spray and robotic spray systems. The full-scale application study performed during this program at Air Force Plant 4 (AFP 4), Ft. Worth, TX on FP 212 and the improved baseline material allowed LM Aero spray operators to become adequately familiar with the spray characteristics of FP 212 so that no additional training will be required once FP 212 is transitioned to production processes. There are not expected to be any mobilization, installation, or training costs as part of the transition from the improved baseline material to FP 212. Since FP 212 is formulated with a lower VOC content than the improved baseline material, there should be no new health and safety requirements that arise from replacing the improved baseline material with FP 212.

The following were key FP 212 design criteria:

- Significant reduction (≥ 75%) of coating application times
- Significant reduction in VOC content (<150 g/L)
- Drop-in replacement for existing coating (improved baseline material)

In order for FP 212 to be listed on the Qualified Products List (QPL) of the Weapon System (WS) of interest, it was tested according to the material specification of the WS of interest by LM Aero under a separate Air Force-funded program shortly after this program began (refer to the report entitled *Zero-VOC Material Development*, available from Ms. Mary Wyderski, ASC/YPVE, WPAFB, OH). It was anticipated that FP 212 would have certain application advantages relative to the initial baseline material. However, since the initial baseline material was replaced by the improved baseline material mid-way through this ESTCP program, the application properties of FP 212 were compared to those of the improved baseline material during full-scale application studies. To compare the durabilities of FP 212 and both of the baseline materials, puffer box testing was performed on FP 212 and the initial baseline material (since the initial baseline material and improved baseline material are both formulated with the same resin, and since the resin is responsible for the durability of a coating, any results from durability testing of the initial baseline material will be valid for the improved baseline material). To compare the failure modes of FP 212 and the improved baseline material, airflow testing was performed on these two materials. Finally, in order to evaluate the flight-worthiness of FP 212, the 150 g/L version of FP 212 and the 40 g/L version of FP 212 were applied to two separate aircraft of the WS of interest on external locations and deployed to an operational base under a separate program funded by the Air Force. The two aircraft were then evaluated during an 18-month Field Service Evaluation (FSE). The flight worthiness of the initial baseline material and improved baseline material had already been verified since the initial baseline material had been operating on the WS of interest for multiple years prior to this program, and since the initial baseline material and improved baseline material are formulated with the same resin system, the flight worthiness of the improved baseline material was verified by the flight worthiness of the initial baseline material. Since the FSE of the two versions of FP 212 were performed under a program separate from ESTCP Project WP-0303, the

results of the FSE will not be covered in detail in this report. For more information concerning the FSE, contact Ms. Mary Wyderski, ASC/YPVE, WPAFB, OH.

As results will show, there will be no improvements in material application rates by FP 212 implementation since the application rates of the initial baseline material were improved to form the improved baseline materials, which has similar application rates compared to FP 212. However, FP 212 has a smoother surface finish than the improved baseline material and can be sprayed to tighter thickness tolerances and should therefore result in less sanding of the dry FP 212 surface compared to the amount of sanding required for the dry surface of the improved baseline material. From a logistical standpoint, replacement of the improved baseline material with FP 212 is not expected to create any added personnel or training requirements. In addition, FP 212 requirements for Personal Protective Equipment (PPE) use will not exceed those of the improved baseline material. The PPE requirement remains unchanged since FP 212 does not introduce any added HAPs or toxic chemicals, while reducing the amount of VOCs released.

## 1.3 PREVIOUS TESTING OF THE TECHNOLOGY

The 150 g/L version of FP 212 was initially tested extensively for physical, mechanical, and chemical/environmental resistance properties for a different WS than the one targeted during this program during a project funded by AFRL/MLSC at WPAFB, OH. Based on the impressive environmental and performance results of FP 212 during the AFRL program, LM Aero worked with the material supplier to decrease the VOC content from 150 g/L to 40 g/L. Following this VOC content reduction, LM Aero performed qualification testing on FP 212 per the material performance specification of the WS targeted during this ESTCP program shortly after this ESTCP program began. The qualification testing of FP 212 per the material performance specification of the WS of interest was performed under a separate project funded by the Air Force. This testing revealed that the physical, mechanical, and chemical/environmental resistance properties of FP 212 were acceptable according to the goals specified in the material performance specification of the WS of interest. During this project, FP 212 also completed an FSE by being applied to two operation aircraft that were monitored for any signs of material degradation or failure over an 18-month timeframe.

## 1.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Once the improved baseline material replaced the initial baseline material, it was the only coating that was qualified to the WS material performance specification for application onto required areas of the WS. Therefore, the successful testing and qualification of FP 212 per the WS material performance specification positioned FP 212 as the only existing alternative to the improved baseline material.

The demonstrated advantages of FP 212 relative to the improved baseline material are as follows:

- lower VOC content (40 g/L vs. 420 g/L)
- decreased sanding time to achieve desired surface finish
- decreased sanding time to achieve desired dry coating thickness

- increased durability

There are limitations to the degree of each of the stated advantages. The solvent package of FP 212 determines the VOC content, and to a large extent, the surface finish of FP 212. The types and quantities of solvents used in the formulation of FP 212 were governed primarily by the requirement to formulate a low VOC coating. The primary solvent used in the formulation of FP 212 is Oxsol 100®. Oxsol 100® is an exempt solvent, which means it is not considered a VOC by EPA standards because it does not react with compounds in the lower atmosphere to form ozone. MPK, which is not an exempt solvent, is also used in the FP 212 formulation and is the main source of FP 212's VOC content. A complete shift to Oxsol 100® in the formulation of FP 212 would have resulted in a VOC content of 0 g/L, but the addition of MPK in the formulation of FP 212 is required to achieve the exceptional application properties that FP 212 exhibits.

It is a requirement for FP 212 and the modified baseline materials to have surface finishes that are relatively smooth. If the surface finishes of the coatings that have reached dry-to-sand time are not sufficiently smooth, sanding of the coating surface is performed until desired smoothness has been reached. FP 212 sprayed to a noticeably smoother surface finish than the improved baseline material, which normally appeared rather grainy and exhibited an orange peel appearance. The improved baseline material would require more sanding time relative to FP 212 to reach required smoothness. The difference in the surface finishes of the two materials is a direct result of the different solvents that are used in the formulations. The solvents in FP 212 produce a relatively smooth surface finish, while the solvents in the improved baseline material produce a relatively rough, orange peel-like surface finish. Consequently, a greater number of labor hours would be required for sanding the improved baseline material to generate acceptable surface finish relative to the amount of sanding required for FP 212.

FP 212 and the improved baseline material are required to be sprayed to a relatively narrow dry thickness range. It was observed by LM Aero spray operators and engineers that FP 212 can be sprayed to tighter dry thickness ranges relative to the improved baseline material. It is speculated that this difference is related to the spray efficiency of FP 212 and the improved baseline material. If the spray efficiency of a material varies while it is being applied, it is difficult to apply the material to a narrow wet thickness range. The spray efficiency of a material is directly related to the viscosity of a material; if the viscosity of a material varies as it is being sprayed, the spray efficiency of a material will also vary. It is speculated that the increase in viscosity of the improved baseline material during a spray trial of a given length is greater than the increase in viscosity of FP 212 during a spray trial of equal length. The relatively consistent viscosity of FP 212 during application most likely results in a relatively consistent spray efficiency, which allows FP 212 be applied to narrower thickness tolerances than the improved baseline material. Erratic spray efficiency of the improved baseline material that is due to a relatively inconsistent viscosity makes it difficult for the spray operator to consistently apply coats at a desired build rate (mils/pass) which makes it difficult to spray to a final thickness that is within the acceptable thickness range. As a result, the cured improved baseline material will require sanding to achieve a dry coating thickness that is within the acceptable range more often than FP 212.

The durability of FP 212 is governed mainly by the type of resin used in its formulation. As described later in this report (Section 4.1 *Performance Data*) puffer box testing demonstrated the durabilities of the 002 resin (used in the formulation of FP 212) and of the 001 resin (used

in the formulation of the initial and improved baseline materials). It was shown that the 002 resin lasts 2 to 3 times longer than the 001 resin in a maritime-simulated environment. For more information on the puffer box test and results, refer to the technical report entitled *FP 212 Puffer Box Testing,* which describes this test and the test results in detail and is available from the Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch (ASC/ENVV).

# 2.0 DEMONSTRATION DESIGN

## 2.1 PERFORMANCE OBJECTIVES

Table 2 presents the performance objectives for this effort and reports whether or not these objectives were met.

**Table 2.** Performance Objectives

| Type of Performance Objective | Primary Performance Criteria | Expected Performance (Metric)* | Actual Performance** | Actual Performance Objective Met?** |
|---|---|---|---|---|
| Quantitative | 1. *Meet or exceed various performance evaluations* | Pass/Fail | Pass | Yes |
| | 2. *Reduce overall application time* | ≥ 75% | 0%*** reduction | No |
| | 3. *Reduce VOC content* | < 150 g/L | 40 g/L**** | Yes |
| | 4. *Reduce Material Usage* | ≥ 50% | 0% reduction | No |
| Qualitative | 1. *Prove as durable as baseline material during Puffer Box testing* | Less cracking, blistering, peeling, or other forms of degradation | Demonstrated less cracking, blistering, peeling, or other forms of degradation | Yes***** |

*Expected performance metrics based on FP 212 advantages relative to initial baseline material, not the improved baseline material

**Actual performance of FP 212 is relative to the improved baseline material

***FP 212 was intentionally applied with the same application methods as the improved baseline material; no attempt was made to maximize FP 212 application properties during this program

****90% reduction in VOC content relative to improved baseline material

*****FP 212 was evaluated for durability along-side the initial baseline material; the durability results of initial baseline material are relevant for improved baseline material since they are both formulated with same resin

The performance of FP 212 was acceptable for all of the tests and demonstrations that were performed during this program. While it may be possible to apply FP 212 with a greater build rate and less time between passes than the improved baseline material, the application method specification for the WS of interest limits the build rate of materials during application, and the minimum time between passes achievable during production processes was used during the full-scale application study performed during this program that provided a side-by-side comparison of the application properties of FP 212 and the improved baseline material. As a result, the full-scale application study was an evaluation of whether or not FP 212 would have acceptable application properties when applied using the same application methods that are used to apply the improved baseline material, which are the most aggressive application methods allowable by the application method specification and that are possible during production processes.

The 40 g/L VOC content of FP 212 is less than the stated goal of >150 g/L for this program and represents a 90 percent reduction from the VOC contents of both the initial and improved baseline materials (420 g/L VOCs).

FP 212 showed no material usage benefits relative to the improved baseline material as recorded during the full-scale application study.

FP 212 proved to be much more durable in a simulated maritime environment than the initial baseline material, which was tested along-side FP 212 during durability testing. The durability testing results for the initial baseline material are relevant for the improved baseline material since both materials are formulated with the same supplier-designated 001 resin, and it is largely the resin that determines the durability of these materials. As a result, it can be concluded that the durability of FP 212 in a simulated maritime environment is much more durable than the improved baseline material.

## 2.2 SELECTING TEST PLATFORMS/FACILITIES

LM Aero facilities at AFP 4, Ft. Worth, TX were selected to perform tests on FP 212 and the baseline materials. This site was selected since it had the facilities and equipment necessary to complete all required testing.

Puffer box testing, which evaluates the durabilities of a material in a simulated maritime environment, was performed on FP 212 and the initial baseline material at AFP 4. The puffer box test article, which LM Aero built and stores at AFP 4, was used to perform this testing.

Lab-scale airflow testing occurred at AFP 4. The subsonic and supersonic airflow test chambers located at AFP 4 were used by LM Aero to perform airflow testing on FP 212 and the improved baseline material under this program.

The full-scale application study performed on FP 212 and the improved baseline material under this program was performed at AFP 4 since the full-scale structure that was used was stored by LM Aero at AFP 4.

The WS for which FP 212 was demonstrated was chosen mainly since LM Aero and Systems Program Office (SPO) managers had identified a need to decrease the VOC content of the initial baseline coating, which has the same VOC content as the improved baseline material.

## 2.3 TEST FACILITY HISTORY/CHARACTERISTICS

Currently, the modified baseline material is applied by LM Aero at AFP 4, Ft. Worth, TX, which is a Government-Owned, Contractor-Operated (GOCO) aircraft manufacturing facility, and has been producing aircraft continuously since 1942. Plant operation has included production involvement in experimental development of nuclear aircraft as well as other advanced tactical fighters. General Dynamics began operating the facility in 1953 until Lockheed Martin took over operation of the facility in 1993. Lockheed Martin works through partnerships with the Department of Defense (DoD) toward their commitment to designing and manufacturing advanced aircraft products.

Science Applications International Corporation (SAIC), Dayton, OH, worked with LM Aero, AFP 4, Ft. Worth, TX to accomplish puffer box testing, air flow testing, and full-scale application studies of FP 212 and the improved baseline material. Test facilities included salt fog, temperature, and humidity chambers for puffer box testing, laboratories and spray booths for conduction testing, air flow chambers for air flow testing, and a full-scale structure that was used during the full-scale application studies.

AFP 4 will benefit from the decreased sanding time of FP 212 relative to the improved baseline material. AFP 4 will also benefit from the decreased VOC content of FP 212 relative to the improved baseline material. FP 212 will be a drop in replacement for the improved baseline material in the current spray systems at AFP 4.

## 2.4 PHYSICAL SET-UP AND OPERATION

FP 212 will be transitioned to production processes at AFP 4, where it will be applied to the WS of interest. Since FP 212 is an admixed material, it will be a drop-in replacement for the improved baseline material. LM Aero became familiar with the application properties of FP 212 during the full-scale application studies, which required FP 212 to be applied to vertically-mounted test panels and a full-scale structure using hand-held spray equipment. As such, minimal training will be required to transition FP 212 to production processes.

## 2.5 SAMPLING/MONITORING PROCEDURES

This section describes parameters that were monitored and monitoring methods that were used while material was being sprayed during the full-scale application studies. Monitoring procedures during material application were critical during the full-scale application studies in order to assess key application properties, such as build rate and time between passes. Monitoring material application during test specimen preparation for airflow testing and puffer box testing was not of particular importance, other than to ensure that test specimen preparation procedures were being followed to prepare proper test panels. As such, monitoring procedures used during test panel preparation for airflow testing and puffer box testing will not be discussed.

During the vertical panel study performed on FP 212 and the improved baseline material, which was performed by LM Aero at AFP 4 on vertically-mounted square panels prior to material application to the full-scale structure, monitoring was completed for the performance parameters listed in Table 3. The objective of this study was to compare the application properties of FP 212 and the improved baseline material on vertically-mounted panels when different application methods were used for each material under “normal” laboratory temperature and humidity conditions [approximately 72°F and 65% Relative Humidity (RH)]. The application methods used during this study were similar to those specified in the application method specification of the WS of interest with some slight deviations, such as varying the time-between passes. Full-scale spray equipment was used to complete this study. The results from the vertical panel study were used to determine precisely what application methods should be used during the full-scale application study to optimize application parameters.

**Table 3. Vertical Panel Study Monitoring**

| Performance Parameter | Monitoring Frequency | Monitoring Method | Demo Plan Deviations |
|---|---|---|---|
| Application temperature | Continuously during build rate trial | Spray booth thermostat | None |
| Application humidity | Continuously during build rate trial | Spray booth humidistat | None |
| Wet mils per pass | Once after each spray pass | Wet mil gauge | Did not determine what max. build rate was for each material |
| Time between passes | Between each spray pass | Time tracking | None |
| Wet coating performance (formation of sags, runs, drips) | During each spray pass | Qualitative visual inspection | None |
| Total wet material thickness | After application of final pass | Wet mil gauge | None |

During the full-scale application study performed by LM Aero at AFP 4 on FP 212 and the improved baseline material, monitoring was accomplished for the listed performance parameters according to the following schedule in Table 4. The objective of this study was to compare the application properties of FP 212 and the improved baseline material when applied to a full-scale structure using the optimum application methods, as determined during the vertical panel study, under "normal" laboratory temperature and humidity conditions. Full-scale production spray equipment was used during this study to apply FP 212 and the improved baseline material to a full-scale structure of a section of the WS of interest that will be coated with FP 212.

**Table 4. Full-Scale Structure Application Study Monitoring**

| Performance Parameter | Monitoring Frequency | Monitoring Method | Demo Plan Deviations |
|---|---|---|---|
| Application temperature | Continuously during prototype trial | Spray booth thermostat | None |
| Application humidity | Continuously during prototype trial | Spray booth humidistat | None |
| Volume of mixed material | Once during each kit mixed | Inventory tracking | None |
| Wet mils per pass | Once after each spray pass | Wet mil gauge | None |
| Time between passes | Between each spray pass | Time tracking | None |
| Wet coating performance (formation of sags, runs, drips) | During each spray pass | Qualitative visual inspection | None |
| Total wet material thickness | After application of final pass | Wet mil gauge | None |
| Total application time | Once during each spray-up | Time tracking | None |
| Total number of passes | Each pass tallied | Visual | None |
| Volume of material used | Once after each spray-up | Weight change of spray equipment | None |
| Volume of waste material | Once after each spray-up | Weight change of spray equipment | None |
| Spray equipment cleaning time | Once after each spray-up | Time tracking | None |
| Volume of solvent used | Once after each spray-up | Inventory tracking | None |

## 2.6 ANALYTICAL PROCEDURES

The cured material parameters that were evaluated during all phases of testing are discussed in this section.

Evaluation of subsonic and supersonic airflow on induced coating failures for panels of FP 212 and the improved baseline material were performed. The objective of this task was to determine if induced failures in panels of each material would propagate when acted upon by airflow and to determine the failure mode of each material. Should either material fail in the form of complete delamination from test panels, this would be cause for concern. Table 5 contains a summary of airflow qualitative test procedures.

**Table 5. Airflow Test Analytical Procedures**

| Analytical Test Procedure | Test Method | Demo Plan Deviations |
|---|---|---|
| Airflow testing of induced coating failures (delamination, failure propagation) | LM Aero method (Qualitative visual inspection) | None |

Table 6 outlines the analytical procedures that were completed as part of the vertical panel study performed on FP 212 and the improved baseline material by LM Aero at AFP 4.

**Table 6. Vertical Panel Study Analytical Procedures**

| Analytical Test Procedure | Test Method | Demo Plan Deviations |
|---|---|---|
| Coating surface appearance | Qualitative visual inspection | None |

Table 7 outlines the analytical procedures that were completed as part of the full-scale application study performed on FP 212 and the improved baseline material by LM Aero at AFP 4.

**Table 7. Full-Scale Structure Application Study Analytical Procedures**

| Analytical Test Procedure | Test Method | Demo Plan Deviations |
|---|---|---|
| Tack-free time | LM Aero method | None |
| Dry-to-sand time | LM Aero method | None |
| Dry mils thickness | ASTM D 1005 | None |
| Coating surface appearance | Qualitative visual inspection | None |

An additional test that is relevant for assessing the performance of FP 212 is puffer box testing. This test evaluates the temperatures, pressures, and exposures that a material experiences when located on certain portions of an aircraft operating continuously in a maritime environment.

The puffer box test article, with the materials applied to it, is subjected to humidity and salt fog exposure, followed by pressure testing, and ends with thermal cycling. This cycle of exposures comprises one block of puffer box testing. Eight total blocks are required for a full evaluation and simulate the exposures and stresses that a coating stack-up would experience on an aircraft operating continuously in a maritime environment for an entire lifetime of 30 years. After each block, the coatings on the test article are visually assessed for any signs of degradation. If coatings degrade significantly prior to completion of the $8^{th}$ block of puffer box testing, they are repaired, and testing continues. This test provided an accurate correlation to how long the coating would last on an aircraft operating in a maritime environment.

Puffer box testing was conducted on FP 212, which is formulated with the 002 resin, and on a the improved baseline material, which is formulated with the 001 resin. Like FP 212, FP 60-2 (the other low VOC, rapid deposition, quick cure coating that was evaluated under ESTCP Project WP-0303, and for which a separate Cost and Performance Report was completed) is formulated with the 002 resin, and like the improved baseline material, FP 60 (the material that will be replaced by FP 60-2) is formulated with the 001 resin. Since the resin is largely responsible for a coating's durability, the puffer box results for FP 212 and the improved baseline material are relevant for assessing the durabilities FP 60-2 and FP 60, respectively. A summary of the puffer box testing performed on FP 212 and the improved baseline material will be summarized in this report. Detailed descriptions of puffer box testing and results are available in the report entitled, *FP 212 Puffer Box Testing*, which is available from ASC/ENVV. Table 8 lists analytical procedures performed during puffer box testing.

**Table 8. Puffer Box Test Analytical Procedures**

| Analytical Test Procedure | Test Method | Demo Plan Deviations |
|---|---|---|
| Puffer Box testing of coating systems (Coating durability) | LM Aero method (Qualitative visual inspection) | None |

# 3.0 PERFORMANCE ASSESSMENT

## 3.1 PERFORMANCE DATA

Table 9 presents a summary of the results from airflow testing of both FP 212 and the improved baseline material. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Airflow Testing* available from ASC/ENVV.

**Table 9. Summary of Airflow Testing Results**

| Coating System and Pre-Conditioning | Outcome (Pass/Fail) |
|---|---|
| FP 212 with no conditioning | Pass |
| FP 212 with 7-day JP8 bath at 140°F | Pass |
| FP 212 with 4-day DI* bath at 120°F | Pass |
| FP 212 with puffer box exposure (two blocks) | Pass |
| Improved baseline material with puffer box exposure (two blocks) | Pass |

*Deionized water

These results demonstrate that FP 212 performs well in high airflow conditions even after exposure to various environments. Simulated coating discrepancies did not propagate or cause more catastrophic coating failures. The FP 212 failure mode observed during testing is acceptable. The performance is also comparable to the improved baseline material.

Results from the vertical panel studies are summarized in Table 10. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Full-Scale Application Study* available from ASC/ENVV.

**Table 10. Summary of Vertical Panel Study Results**

| | | Improved Baseline Material | FP 212 |
|---|---|---|---|
| Spray Trial | Dwell Time* (MIN) | Outcome (Pass/Fail) | Outcome (Pass/Fail) |
| 1 | 5 | Pass | Pass |
| 2 | 0 | Pass | Pass |
| 3 | 3 | Pass | Pass |

*Time between passes

For each of the three spray trials, both materials were applied at the same build rate but the dwell time (time waited between passes) was varied. During the first spray trial, LM Aero waited 5 minutes between each pass. The surface finish of both coatings looked good, with FP 212 exhibiting a smoother surface finish than the improved baseline material. The spray operator commented that 5 minutes between passes was an excessive dwell time since FP 212 began to show signs of significant

curing in the 5 minute wait between passes, which adversely impacted the surface finish of subsequent coats. During the second spray trial, LM Aero used a continuous spray method by having no dwell time between passes; immediately after one coat was complete, LM Aero began spraying the next coat. The improved baseline material began to show signs of sagging after several continuous coats had been applied. FP 212 showed no signs of sagging after exceeding the number of coats at which the improved baseline material began to sag. The second spray trial for FP 212 ended at this point. The rationale for using this application method during the second spray trial was for information gathering purposes only. Even though a continuous application method is not a realistic possibility in a production environment with FP 212 and the baseline material, it was of interest to determine if one material could be applied continuously for more coats than the other before sagging was observed or until one coating had surpassed the number of coats that were applied at which the other coating began to sag. During the third spray trial, LM Aero waited 3 minutes between passes. The surface finishes of the two materials look good, but the surface finish of FP 212 was smoother than the surface finish of the improved baseline material, which exhibited a noticeable orange peel appearance and appeared rather grainy.

Following the vertical panel study, FP 212 and the improved baseline material were applied to a full-scale structure of an aircraft that had been taken out of service. Both materials were applied to the full-scale structure using the same build rate that was used for all 3 spray trials during the vertical panel study and were applied using a 3 minute dwell time. One material was applied at a time and then peeled off of the full-scale structure (a release agent was applied to the substrate prior to each spray trial so materials could be easily removed at the conclusion of each spray trial). This process was performed 3 times for each material so that average values for the data collected during material application could be calculated. The average results from the full-scale structure application study were evaluated. Table 11 summarizes the percent difference of FP 212 relative to the improved baseline material for properties for which it was desired that FP 212 have advantages relative to the improved baseline material. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Full-Scale Application Study* which is available from ASC/ENVV.

**Table 11. Summary of Averaged Full-Scale Application Study Results**

| Parameter | Percent Differenct between FP 212 and Improved Baseline Material* |
|---|---|
| Total Passes** | No difference |
| Wet Build Rate | -3.9% |
| Final Wet Thickness | -3.9% |
| Total Application Time*** | No difference |
| Dry-to-Sand Time | No difference |
| Total time from Start of Application to Dry-to-Sand | No difference |
| Total Amount of Material Sprayed | No difference |

*Performance of FP 212 relative to the improved baseline material

**Total passes required to build up to desired wet thickness

***Start of material application to completion of final pass

As Table 11 shows, the measured application properties of FP 212 and the improved baseline material are almost identical. The same number of passes was used by the spray operator to build the materials up to desired wet thickness. However, the wet build rate (mils per pass) for FP 212 was slightly lower compared to the build rate for the improved baseline material. This slight difference can most likely be attributed to variation in spray operator application methods when applying the two materials and not to inherent differences in the build rate capabilities of the two materials. The slightly lower build rate used for FP 212 resulted in a slightly lower final wet thickness than the improved baseline material. However, the final wet thickness of the improved baseline material, while slightly greater than the final wet thickness of FP 212, was slightly higher than desired. This is most likely the result of the spray operator having less control over the build rate of the improved baseline material relative to FP 212. As explained in Section 2.4 *Advantages and Limitations of the Technology,* this can most likely be attributed to the relatively great change in viscosity of the improved baseline material, which results in relatively inconsistent spray efficiency compared to FP 212. There was no difference between the two materials in the other properties (application time, cure time, material usage) for which it was desired for FP 212 to have advantages relative to the improved baseline material. Since this full-scale application study was performed with the intent of applying both materials with the same build rate and time between passes, the results for those properties that are dependent on the application methods used by the spray operator (build rate, application time) were almost identical. There was also no difference, however, between the properties of the two materials that are independent of the methods the spray operator uses to apply the materials (cure time and material usage). As a result, there are expected to be no labor hours, cure time, nor material usage advantages realized by replacing the improved baseline material with FP 212.

As mentioned in Section 2.4 *Advantages and Limitations of the Technology,* FP 212 had a smoother surface finish relative to the surface finish of the improved baseline material due to the different solvents that are used in the formulation of FP 212 compared to the improved baseline material. This should lead to decreased labor hours required for sanding for purposes of achieving desired smooth surface finish for FP 212 relative to the labor hours that will be required to sand the cured improved baseline material. Additionally, as a result of having relatively consistent viscosity during application, FP 212 should be able to be applied to tighter thickness ranges relative to the improved baseline material, which should lead to few labor hours required for sanding for purposes of achieving desired final dry thickness as compared to the hours that will be required to sand the cured improved baseline material to achieve desired final dry coating thickness.

Since full-scale production equipment and full-scale structures were used during this study, the results require no extrapolation to what should occur during production processes; these results are highly accurate and representative to what should occur during production activities. The advantages of FP 212 relative to the improved baseline material that were revealed during the full-scale application study support the implementation of FP 212 into production processes.

The final performance data for FP 212 are the puffer box test results. As described in Section 3.6 *Analytical Procedures*, puffer box testing results are valid for the improved baseline material even though it was not tested along-side FP 212 since this test was performed on the initial baseline material, and the initial baseline material is formulated with the same resin (001 resin) as the improved baseline material. In contrast, FP 212 was formulated with the 002 resin. The only notable differences between the initial baseline material and the improved baseline material are

that they have different solvent packages, but this difference has no impact on the durabilities of either coating. After the fourth block of testing, the initial baseline material had degraded to the point that the majority of it had to be repaired prior to the start of the fifth block of testing. By the end of the seventh block of testing, the initial baseline material had again degraded to the point that the majority of it needed to be repaired. Puffer box testing then continued through 3 additional blocks of testing, for a total of 10 blocks. The FP 212 material showed virtually no degradation during puffer box testing. Figures 1 and 2 shows the puffer box after the completion of block 4, which approximates 15 years of operation in a maritime environment.

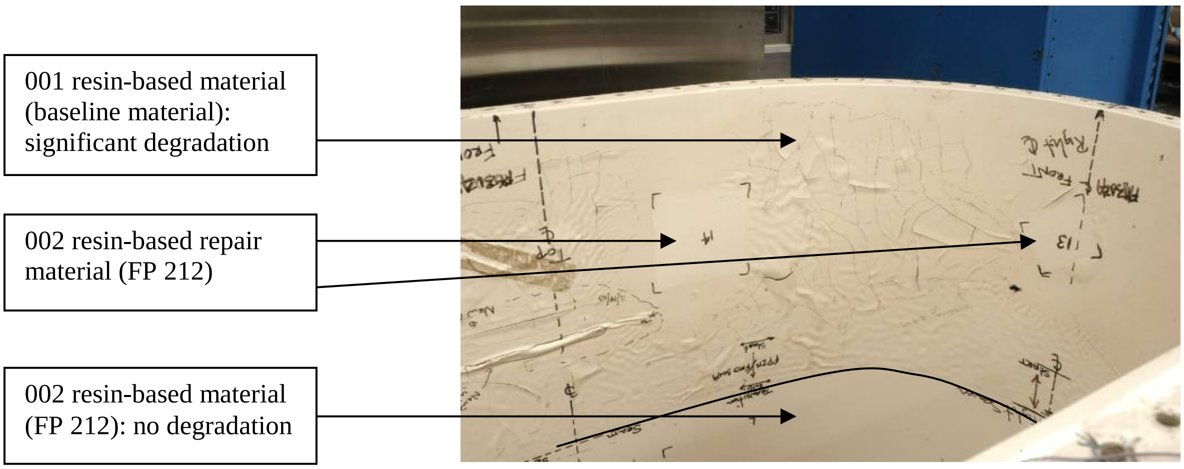


**Figure 1. Puffer Box After Block 4**

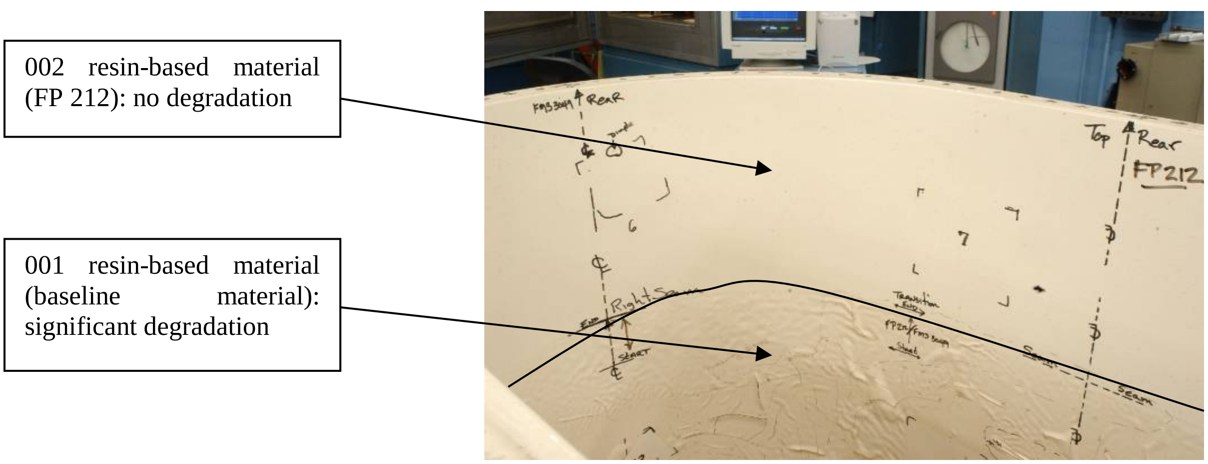


***Figure 2. Puffer Box After Block 4***

In Figures 1 and 2, the visible layer of material is a material applied over FP 212 and the initial baseline material. The only difference in the material stack-ups of the puffer box on each side of the black dividing line in Figures 1 and 2 is either FP 212 or the initial baseline material. As a result, the degradation seen in Figures 1 and 2 can be solely attributed to either FP 212 or the initial baseline material. Figure 1 shows significant cracking and blistering of the initial baseline material

that is formulated with the 001 resin, which is the same 001 resin used in the formulation of the improved baseline material. The unblemished 002 resin-based material (FP 212) is shown in Figure 1 in repair patches made in the midst of the initial baseline material and below the black dividing line that separates the initial baseline material and FP 212. Figure 2 is a picture of the puffer box that has been turned over to give a better view of the unblemished, undegraded FP 212 material. By the end of the tenth block of testing, FP 212 looked nearly the same as it does in Figures 1 and 2.

As described in Section 3.6 *Analytical Procedures*, puffer box testing results are valid for FP 60-2 (the other low VOC aerospace coating tested during ESTCP Project WP-0303) and for FP 60 (the material that FP 60-2 will replace) since this test was performed on FP 212 and the initial baseline material, and FP 60-2 and FP 60 are formulated with the same resins as FP 212 and the initial baseline material, respectively.

It needs to be stressed that the initial baseline material is not an unacceptable material; it has been operating on a legacy WS for multiple years. Figures 1 and 2 simply show that 002 resin-based materials are more durable in maritime environments than 001 resin-based materials. The legacy WS does not primarily operate in maritime environments so durability of the legacy material in a maritime environment is not as much of a concern as it is for FP 60-2, which will be applied to aircraft that operate primarily in maritime environments.

Puffer box test results indicate that the 002 resin lasts 2 to 3 times longer on an aircraft operating in a maritime environment than the 001 resin currently used in the baseline coatings that FP 212 and FP 60-2 will replace. According to LM Aero engineers, the puffer box test has a high degree of accuracy in terms of the overall exposures and stresses that a material will experience when applied to an actual aircraft operating in a maritime environment. The 001 resin degradation observed in the puffer box correlates extremely well with degradation observed in 001 resin applied to legacy aircraft operating in maritime environments. The increased durability of the 002 resin will result in significant environmental and Life-Cycle Cost (LCC) reductions for the FP 60-2-targeted WS of interest as the number of repairs required on aircraft operating in maritime environments will be significantly reduced. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Puffer Box Testing* available from ASC/ENVV.

## 3.2 PERFORMANCE CRITERIA

Table 12 lists the performance criteria that were developed during completion of the demonstration plan for this program.

**Table 12. Performance Criteria**

| Performance Criteria | Description | Primary or Secondary |
|---|---|---|
| Product Testing | *1. Must prove at least as durable as baseline material in puffer box test* | *Primary* |
| Hazardous Materials | *Measure VOC content of FP 212 and compare to baseline material* | *Primary* |
| Ease of Use | *1. Compare maximum application properties to baseline coating during full-scale application study*<br>*2. Assess material usage*<br>*3. Drop-in replacement for baseline material* | *Primary* |
| Maintenance/ Reliability | *Record frequency and magnitude of repairs to FP 212 vs. baseline material during puffer box test* | *Secondary* |
| Versatility | *Ensure technical interchange with other weapon systems offices interested in 002 resin-based coatings* | *Secondary* |

Table 13 outlines the actual performance criteria that were used to assess FP 212 and the methods used to confirm the performance of FP 212.

**Table 13. Expected and Actual Performance Criteria and Performance Confirmation Methods**

| Expected Performance Criteria | Expected Performance Metric | Performance Confirmation Method | Actual Performance Criteria |
|---|---|---|---|
| **PRIMARY CRITERIA (Performance Objectives) (Quantitative)** | | | |
| Hazardous Materials | *Reduce VOCs by 75%* | Rule 1124 AVAQMD | Hazardous Materials |
| Ease of Use<br>- Cure time<br>- Build rate<br>- Sprayability<br>- Overall application time<br>- Material usage | *Prove to have similar sprayability properties to baseline material*<br>*Reduce overall application time by 75%*<br>*Reduce material usage by 50%*<br>*Prove to be a drop-in replacement for baseline material* | *Monitor and measure sprayability, application properties, and material usage during full-scale application studies* | Ease of Use<br>- Cure time<br>- Build rate<br>- Sprayability<br>- Overall application time<br>- Material usage |
| **PRIMARY PERFORMANCE CRITERIA (qualitative)** | | | |
| Product Testing | *As durable as baseline in puffer box* | *Visual observation, picture documentation* | Product Testing |
| **SECONDARY PERFORMANCE CRITERIA (qualitative)** | | | |
| Maintenance/Reliability | *Less maintenance and lesser degree of repairs required for FP 212 compared to baseline* | *Record repairs made to FP 212 material and degree of repair during puffer box testing* | Maintenance/Reliability |
| Versatility | *Increase interest in and achieve risk reduction for other platforms interested in 002 resin-based coatings* | *Invite representatives from interested WS SPOs to technical interchange meetings* | Versatility* |

*Versatility was achieved in the form of additional application of 002 resin besides FP 212 for the WS of interest

## 3.3 DATA EVALUATION

The 90 percent reduction in VOC content of FP 212 relative to the improved baseline material (420 g/L vs. 40 g/L) should result in life-cycle reductions in VOC and Hazardous Air Pollutant (HAP) emissions for the WS of interest. Table 14 shows expected life-cycle reductions in VOC and HAP emissions for the WS of interest.

**Table 14. Expected VOC and HAP Life-Cycle Reductions for the WS of Interest**

| Pollutant | Emissions Reduction (lbs.) |
|---|---|
| VOC | 11,131 |
| HAP | 12,938 |

FP 212 airflow testing results showed that induced flaws in FP 212 do not propagate when acted upon by airflow and that the failure mode of FP 212 in high airflow conditions is acceptable. FP 212 showed exceptional application properties during the full-scale application study results. The fact that full-scale equipment and structures were used during the full-scale application study allows the results to be credible for what should occur during production operations. Finally, the 002 resin durability was an unexpected benefit of FP 212 relative to the improved baseline material.

## 3.4 TECHNOLOGY COMPARISON

Overall, FP 212 showed environmental and application improvements relative to the improved baseline material. The performance of FP 212, combined with the fact that it is a drop-in replacement for the improved baseline material and that it does not pose increased risk to worker health, makes FP 212 a viable replacement for the improved baseline material.

With a 90 percent decrease in VOC levels, FP 212 should perform better than the improved baseline material from an environmental stand-point. On a per aircraft basis, VOC emissions at production facilities should decrease when FP 212 replaces the baseline material, which will improve work-place safety and decrease regulatory burdens. From a production stand-point, FP 212 should decrease the level of sanding required relative to the improved baseline material. As a result, labor hours for sanding per aircraft should decrease. The increased durability of FP 212 compared to the improved baseline material in maritime environments should result in environmental and economic benefits over the life-cycle of any aircraft of the WS of interest that operate continuously in maritime environments, but there are not expected to be a significant number of these aircraft, if any at all, of the WS of interest. Repairs resulting from the improved baseline material degradation in maritime environments would result in aircraft downtime, material purchase/usage, labor hours, and VOC emissions to make Programmed Depot Maintenance (PDM)-level repairs. Implementation of FP 212 would significantly decrease the

frequency and level of repairs for aircraft operating continuously in maritime environments and all associated costs over the WS lifetime.

Additionally, as a result of this program, other 002 resin-based materials besides FP 212 have been qualified and transitioned to the WS of interest to replace baseline coatings other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. The testing of the additional 002 resin-based coatings was performed under a separate Air Force program that ran parallel to this program. It was outside the scope of this program to evaluate any coating other than FP 212 since it was not known until near the end of this program that the 002 resin would revolutionize the coating stack-up of the WS of interest. Therefore, the environmental and economic benefits resulting from this program as summarized in this report could be extremely conservative if the other 002 resin-based materials have environmental and economic advantages relative to the materials that they replaced. The benefits to the WS of interest as a result of this program could be orders of magnitude higher than the level of benefits summarized in this report.

There are no other technologies in addition to FP 212 that are being tested as alternatives to the improved baseline material.

# 4.0 COST ASSESSMENT

## 4.1 COST REPORTING

The cost assessment completed for this program follows the general format of the Environmental Cost Analysis Methodology (ECAM) that was developed by the National Defense Center for Environmental Excellence (NDCEE). A Level II ECAM analysis was performed on the technology demonstrated during this program. During puffer box testing and the full-scale application study, direct comparisons of FP 212 and the improved baseline material were completed to evaluate properties that impact cost and performance and that therefore impact an ECAM. Puffer box testing closely mimics the temperatures, pressures, and exposures that a material experiences on an aircraft operating continuously in a maritime environment. This conclusion is based on field reports, including pictures, of 001 resin that has been applied to aircraft operating continuously in maritime environments. The field reports have proven the high degree of correlation of puffer box test results with the degradation that occurs on actual aircraft. However, there are such a small number of aircraft of the WS of interest that operate continuously in maritime environments that the increased durability of FP 212 relative to the improved baseline material will result in negligible LCC reductions for the WS of interest. As a result, increased durability of FP 212 relative to the improved baseline material was not considered in the calculations of LCC reductions of replacing the improved baseline material with FP 212.

In order to compare application properties of FP 212 and the improved baseline material, a full-scale application study was performed. The results from this study are highly accurate at determining what the application benefits of FP 212 will be compared to the improved baseline material during actual production implementation of FP 212 since this study was performed using full-scale spray equipment and a full-scale structure. The full-scale application study results were used to estimate the labor hour reductions that should result by transitioning FP 212. Relevant personnel at the production facilities where FP 212 will be transitioned were consulted to determine if and to what extent the Operations and Maintenance Costs, Indirect Environmental Activity Costs, and Other Costs would change if the improved baseline material was replaced with FP 212.

Tables 15 and 16 below summarize the Direct Environmental Activity Process Costs and Indirect Environmental Activity Costs for the improved baseline material and FP 212. This assessment utilizes a basis founded on *per weapon system* costs for the purpose of cost reporting.

## Table 15. ECAM Cost Reporting Table for Improved Baseline Material

| Direct Environmental Activity Process Costs: Start-Up | | Direct Environmental Activity Process Costs: Operations & Maintenance | | Indirect Environmental Activity Costs | | Other Costs | |
|---|---|---|---|---|---|---|---|
| **Activity** | **Unit $** | **Activity** | **Unit $** | **Activity** | **Unit $** | **Activity** | **Unit $** |
| **SUNK COSTS FOR BASELINE** | | Labor for material application / management of hazardous waste | NC | Compliance audits | NC | **NOT WITHIN THE SCOPE OF THIS PROGRAM** | |
| | | Labor for sanding | **$10,000** | Document Maintenance | NC | | |
| | | Utilities | NC | Envr. Mmgt. Plan development & maintenance | NC | | |
| | | Mgmt/Treatment of by-products | NC | Reporting requirements | NC | | |
| | | Hazardous waste disposal fees | NC | Test/analyze waste streams | NC | | |
| | | Coating materials | **$5,700** | Medical exams (including loss of productive labor) | NC | | |
| | | Process chemicals, Nutrients | NC | Waste transportation (on and off-site) | NC | | |
| | | Consumables and supplies | NC | OSHA/EHS training | NC | | |
| | | Equipment maintenance | NC | | | | |
| | | Training of operators | NC | | | | |
| **Totals Per Unit** | | | **$15,700** | | **NC** | | |

*No Change (NC) relative to FP 212 (costs held constant)*

## Table 16. ECAM Cost Reporting Table for FP 212

| Direct Environmental Activity Process Costs — Start-Up | | Operations & Maintenance | | Indirect Environmental Activity Costs | | Other Costs | |
|---|---|---|---|---|---|---|---|
| **Activity** | **Unit $** | **Activity** | **Unit $** | **Activity** | **Unit $** | **Activity** | **Unit $** |
| Facility preparation, mobilization | NC | Labor for material application / management of hazardous waste | NC | Compliance audits | NC | NOT WITHIN THE SCOPE OF THIS PROGRAM | |
| Equipment Design | NC | Labor for sanding | **$7,000** | Document Maintenance | NC | | |
| Equipment purchase | NC | Utilities | NC | Envr. Mmgt. Plan development & maintenance | NC | | |
| Installation | NC | Mgmt/Treatment of by-products | NC | Reporting requirements | NC | | |
| Training of operators | NC | Hazardous waste disposal fees | NC | Test/analyze waste streams | NC | | |
| | | Coating materials | **$7,500** | Medical exams (including loss of productive labor) | NC | | |
| | | Process chemicals, Nutrients | NC | Waste transportation (on and off-site) | NC | | |
| | | Consumables and supplies | NC | OSHA/EHS training | NC | | |
| | | Equipment maintenance | NC | | | | |
| | | Training of operators | NC | | | | |
| **Totals Per Unit** | **NC** | | **$14,500** | | **NC** | | |

*No Change (NC) relative to improved baseline material (costs held constant)*

As Tables 15 and 16 show, the most significant economic benefits of FP 212 will be the reduction in labor hours for production processes as a result of decreased sanding requirements. Estimated application costs and Operations and Maintenance (O&M) costs on a per aircraft basis for the improved baseline material are $15,700 and for FP 212 are $14,500 for a reduction in total per unit costs of $1,200.

Tables 15 and 16 indicate that the transition to FP 212 will have no impact on Indirect Environmental Activity Costs. The 90 percent reduction in VOC content of FP 212 relative to the improved baseline material (40 g/L vs. 420 g/L) will result in life-cycle reductions in VOC and HAP emissions. It is estimated that life-cycle VOC and HAP emissions of the WS of interest will be reduced by 11,131 pounds and 12,938 pounds, respectively, by replacing the improved baseline material with FP 212 in production operations. However, according to the facilities personnel who were consulted during this project who are located at facilities where FP 212 will be transitioned, the decrease in VOC and HAP reductions will most likely have no impact on Indirect Environmental Activity Costs.

The demonstration of FP 212 was funded jointly by AFRL/MLSC, ASC/ENVV, and ESTCP at a total cost of approximately $488K, with ESTCP contributing approximately $421K. In-kind support from LM Aero is not included in the $488K. The result of this investment was a fully-qualified, drop-in alternative for the improved baseline material. As such, there will be no additional operational costs to implement FP 212.

## 4.2 COST ANALYSIS

In order to evaluate the cost performance of this program and the transition of FP 212, the series of negative cash flows that occurred to execute this program and the series of positive cash flows that are expected to occur once FP 212 is implemented are evaluated. Tables 17 and 18 report the negative cash flows (costs) that resulted from the cost of the FP 212 demonstration and the positive cash flows [expected annual cost savings (benefits)] once FP 212 is implemented, the present values of the costs and benefits, and the difference between the present values of the benefits and costs, which is the Net Present Value (NPV) of the series of negative and positive cash flows. Table 17 reports these financial metrics on a DoD-wide basis that includes costs contributed by AFRL/MLSC, ASC/ENVV, and ESTCP. Table 18 reports these financial metrics on an ESTCP basis that includes costs contributed by ESTCP only. The positive cash flows (expected annual benefits) reported in Tables 17 and 18 are the same since they both reflect the benefits that should occur once FP 212 replaces the improved baseline material. The only difference between Tables 17 and 18 is the series of negative cash flows (costs) that occurred as the funding for the FP 212 demonstration was exhausted during the execution of this program. The negative cash flows in Table 17 represent the annual funding contributions by AFRL/MLSC, ASC/ENVV, and ESTCP combined (a total of approximately $488K) for the execution of the FP 212 portion of this ESTCP program. The negative cash flows in Table 18 represent the annual funding contributions by ESTCP only (a total of approximately $421K) for the execution of the FP 212 portion of this ESTCP program.

**Table 17. DoD-Wide Life-Cycle Cost Savings for FP 60-2 Implementation**

| Fiscal Year | 2001 | 2003 | 2004 | 2005 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | -6 | -4 | -3 | -2 | 1 | 2 | 3 | 4 | 5 | 6 |
| Benefits | | | | | $30,000 | $28,800 | $26,400 | $24,000 | $24,000 | $7,200 |
| Costs | | $137,435 | $138,508 | $212,500 | | | | | | |

**Present Benefits =** $128,859.55

**Present Costs =** $529,999.20

**NPV =** **($401,139.65)**

**Table 18. ESTCP Life-Cycle Cost Savings for FP 60-2 Implementation**

| Fiscal Year | 2001 | 2003 | 2004 | 2005 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | -6 | -4 | -3 | -2 | 1 | 2 | 3 | 4 | 5 | 6 |
| Benefits | | | | | $30,000 | $28,800 | $26,400 | $24,000 | $24,000 | $7,200 |
| Costs | | $89,500 | $118,508 | $212,500 | | | | | | |

**Present Benefits =** $128,859.55

**Present Costs =** $454,466.21

**NPV =** **($325,606.66)**

Since FP 212 is a drop-in replacement for the improved baseline material, there will be no additional out-year operational costs by replacing the improved baseline material with FP 212. As a result, the only negative cash flows that occur are due to the costs of the FP 212 demonstration (the costs of executing this ESTCP program). Once FP 212 is implemented, positive cash flows will result as the expected economic savings of FP 212 begin to be realized. The present values of the negative cash flows (costs) and positive cash flows (benefits) were determined by using an extrapolated Office of Management and Budget (OMB) discount rate of 3.0 percent based on the selected ECAM evaluation period of 6 years. The 6-year evaluation period was selected to fully account for the expected remaining production schedule of the WS of interest. The 3.0 percent discount rate accounted for the time value of money and permitted the estimation of life-cycle cost savings for government and Original Equipment Manufacturer (OEM) implementation of FP 212.

As reported in Tables 17 and 18, the present values of the benefits are less than the present values of the costs, resulting in total NPV of -$401K and -$326K for DoD as a whole and for ESTCP, respectively. The cumulative expected annual benefits of replacing the improved baseline material with FP 212 are less than the total cost of executing this program. As a result, the costs of demonstrating and validating FP 212 will not be recovered (paid back). The estimated Internal Rates of Return (IRRs) based on DoD-wide and ESTCP contributions are -18.6 percent and -17.0% percent, respectively. Table 19 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP, based on the benefits of FP 212 relative to the improved baseline material.

**Table 19. Summary of Expected Financial Metrics Resulting from Implementation of FP 212**

| Financial Metric | DoD-Wide Contributions | ESTCP Contributions Only |
|---|---|---|
| NPV | -$401K | -$326K |
| Payback Period | N/A* | N/A* |
| IRR | -18.6% | -17.0% |

*The total expected positive cash flows (estimated cumulative annual cost savings) are lower than the total negative cash flows (cost of the FP 212 testing and demonstration)

The expected annual benefits reported in Table 19 may be conservative since, as a result of this program, LM Aero and SPO engineers decided to transition other 002 resin-based materials besides FP 212 to the WS of interest to replace baseline materials other than the improved baseline material that were formulated with the 001 resin and that covered a significant portion of the aircraft. If these other 002 resin-based materials have surface finish and thickness accuracy benefits relative to the 001 resin-based materials that they replace that are similar to those that FP 212 has relative to the improved baseline material, then the results of this program are expected to substantially increase the level of economic savings for the WS of interest. If the increased level of annual benefits are increased, then the NPV and IRR may be positive and the costs of demonstrating and validating FP 212 may be recovered.

The major cost drivers associated with the improved baseline material are: (1) relatively rough surface finish, (2) relatively low wet material thickness accuracy. These cost drivers lead to

relatively high labor and material application costs and lengthy flow times. FP 212 has advantages relative to the improved baseline material in both of the stated cost driver categories. However, one cost advantage that the improved baseline material has relative to FP 212 is the price per kit (half-gallon) of material. The improved baseline material costs 31 percent less than FP 212 on a per-kit basis, which adversely impacted the financial metrics of this project.

Table 20 provides the results of a sensitivity analysis performed on the major cost drivers for FP 212.

**Table 20. FP 212 Sensitivity Analyses of Cost Drivers**

| **Sensitivity Analysis:** | | |
|---|---|---|
| Overall DoD NPV | Simulation Mean = | -$401,186.73 |
| | Simulation Sigma = | $131,603.47 |
| ESTCP NPV | Simulation Mean = | -$325,653.73 |
| | Simulation Sigma = | $131,603.47 |
| | Trials = | 250 |
| | | |
| **95% Confidence Interval:** | | |
| Overall DoD NPV | Lower Bound = | -$417,500.17 |
| | Upper Bound = | -$384,873.30 |
| ESTCP NPV | Lower Bound = | -$341,967.17 |
| | Upper Bound = | -$309,340.30 |

Based on a simulation size of 250 trials, the FP 212 95 percent Confidence Interval (CI) for DoD-wide NPV equals a loss of between $417,500.17 and $384,873.30. Similarly the 95 percent CI for ESTCP NPV equates to a loss of between $341,967.17 and $309,340.30 over the remaining weapon system production cycle.

## 4.3 COST COMPARISON

Due to replacing the initial baseline material, over which FP 212 was expected to have significant application benefits, with the improved baseline material, which has better application properties compared to the initial baseline material, the expected annual and economic benefits of this program were not as significant as initially estimated. However, FP 212 is still expected to achieve annual environmental and economic benefits by replacing the improved baseline material, but the annual production rates of the WS of interest are dwindling, and production of the WS of interest will cease in a few years. As a result, there will not be a sufficient number of aircraft to which the per-aircraft economic benefits of FP 212 can be applied to recover the cost of executing this program.

While the environmental benefits of this program will most likely not result in economic savings, they are still considered and quantified for the positive impacts they will have on the environment

and human health.  The release of VOC and HAP emissions into the Earth's atmosphere impacts air quality and increases the risk of health problems.  VOCs have been shown to contribute to the formation of ground-level ozone, which is a pollutant and can lead to severe respiratory problems and can damage crops and vegetation.  HAPs are known or suspected carcinogens.  Through the use of FP 212, approximately 11,131 pounds of VOC emissions and 12,938 pounds of HAP emissions will be eliminated from the remaining production operations of the WS of interest.

# 5.0 PERFORMANCE ANALYSIS – OVERALL ESTCP PROJECT WP-0303

As mentioned in Section 1.1 *Scope of ESTCP Project WP-0303*, this ESTCP project involved the testing and demonstration of two low VOC, rapid deposition, quick cure aerospace coatings, FP 60-2 and FP 212, in addition to the baseline coatings that will be replaced by FP 60-2 and FP 212. The financial metrics reported in Sections 5.1 – 5.3 of this report took into consideration the costs of testing and demonstrating FP 212 and the expected annual benefits of replacing the improved baseline material with FP 212. In order to provide an evaluation of environmental performance and cost effectiveness of the overall ESTCP Project WP-0303, the costs and benefits associated with testing and demonstrating FP 60-2 and replacing FP 60 (the baseline material of the FP 60-2-targeted WS) with FP 60-2 need to be combined with those of FP 212 summarize in this report.

## 5.1 ENVIRONMENTAL PERFORMANCE ANALYSIS – OVERALL ESTCP PROJECT WP-0303

Table 21 reports the expected VOC and HAP emissions reductions by replacing FP 60 with FP 60-2. The justification for the information reported in Table 21 is detailed in the ESTCP Cost and Performance Report for FP 60-2, which is available from ESTCP.

**Table 21. Expected VOC and HAP Life-Cycle Reductions for the FP 60-2-Targeted Weapon System of Interest**

| Pollutant | Emissions Reduction (lbs.) |
|---|---|
| VOC | 386,840 |
| HAP | 447,625 |

Table 21 reports that there are expected to be significant VOC and HAP emissions reductions for the FP 60-2-targeted WS of interest if FP 60-2 replaces FP 60. The emissions reductions reported in Table 21 significantly increase the expected emissions reductions of the overall ESTCP Project WP-0303. However, as specified in the FP 60-2 Cost and Performance Report, which is available from ESTCP, LM Aero and SPO engineers decided to transition other 002 resin-based materials besides FP 60-2 to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that were formulated with the 001 resin and that covered a significant portion of the aircraft. Consequently, the environmental benefits for the FP 60-2-targeted WS of interest are expected to be significantly greater than those reported in Table 21 due to the increased durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments since fewer repairs will be required to the FP 60-2-targeted WS of interest.

Table 22 reports the expected emissions reductions for the overall ESTCP Project WP-0303 by combining the reductions in Table 21 with those of FP 212 in Table 14.

**Table 22. Expected VOC and HAP Life-Cycle Reductions for the FP 60-2 and FP 212-Targeted Weapon Systems of Interest**

| Pollutant | Emissions Reduction (lbs.) |
|---|---|
| VOC | 397,971 |
| HAP | 460,590 |

As Table 22 reports, the expected emissions reductions for the overall ESTCP project are significant. The replacement of FP 60 by FP 60-2 accounts for the majority of the expected emissions reductions, but replacing the baseline material of the FP 212-targeted WS of interest with FP 212 adds to the expected emissions reductions. However, the emissions reductions estimates reported in Table 22 are extremely conservative since, as a result of this program, other 002 resin-based materials besides FP 60-2 will be transitioned to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that are formulated with the 001 resin and that cover a significant portion of the aircraft. The increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments will lead to fewer repairs, which will decrease the level of VOC and HAP emissions from applying materials during repair processes. Also, as a result of this program, other 002 resin-based materials besides FP 212 will be transitioned to the FP 212-targeted WS of interest to replace baseline materials other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. If the other 002 resin-based materials besides FP 212 have environmental advantages relative to the 001 resin-based materials that they replace, then the environmental benefits of this program will be increased even more.

Additionally, as a result of this ESTCP project, LM Aero and certain SPO personnel are considering the transition of 002 resin-based materials to a WS other than the FP 60-2-targeted WS and other than the FP 212-targeted WS. This additional WS is currently coated primarily with 001 resin-based materials and will benefit greatly from the increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments since many of the aircraft of this additional WS operate continuously in maritime environments. Therefore, as a result of this ESTCP project, at least two (and possibly three) DoD WS platforms will benefit greatly, and the environmental benefits for DoD should be orders of magnitude higher than those summarized in this report.

## 5.2 ECONOMIC PERFORMANCE ANALYSIS – OVERALL ESTCP PROJECT WP-0303

Table 23 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP only, based on the benefits of FP 60-2 relative to FP 60. The justification for the information reported in Table 23 is detailed in the ESTCP Cost and Performance Report for FP 60-2, which is available from ESTCP.

**Table 23. Summary of Expected Financial Metrics Resulting from Implementation of FP 60-2**

| Financial Metric | DoD-Wide Contributions | ESTCP Contributions Only |
|---|---|---|
| NPV | $47.3 million | $47.8 million |
| Payback Period | <1 year | <1 year |
| IRR | 36.9% | 49.5% |

As Table 23 shows, the NPV on a DoD-Wide basis and for ESTCP are both extremely positive for the FP 60-2 portion of this program. Using a simple payback period calculation, the payback period is expected to be less than a year, and the IRR for the DoD-wide and ESTCP-only contributions are extremely attractive.

Table 24 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP for the overall ESTCP Project WP-0303.

**Table 24. Summary of Expected Financial Metrics Resulting from Implementation of FP 60-2 and FP 212**

| Financial Metric | DoD-Wide Contributions | ESTCP Contributions Only |
|---|---|---|
| NPV | $46.9 million | $47.5 million |
| Payback Period | <1 year | <1 year |
| IRR | 30.9% | 39.7% |

As reported in Table 19, even though the financial metrics for the FP 212 portion of ESTCP Project WP-0303 are negative, the overall financial metrics for ESTCP Project WP-0303 are extremely attractive, as Table 24 reports, due to the substantial economic benefits that are expected to result by replacing FP 60 with FP 60-2, as reported in Table 23. However, the financial metrics reported in Table 24 are extremely conservative since, as a result of this program, other 002 resin-based materials besides FP 60-2 will be transitioned to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that were formulated with the 001 resin and that cover a significant portion of the FP 60-2-targeted WS of interest. The increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments will lead to fewer repairs, which will decrease the labor hours and labor costs for material removal and re-application and material purchase costs associated with making repairs. Also, as a result of this program, other 002 resin-based materials besides FP 212 will be transitioned to the FP 212-targeted WS of interest to replace baseline materials other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. If the other 002 resin-based materials besides FP 212 have economic advantages relative to the 001 resin-based materials that they replace, then the economic benefits of this program will be increased even more.

Additionally, as a result of this ESTCP project, LM Aero and certain SPO personnel are considering the transition of 002 resin-based materials to a WS other than the FP 60-2-targeted WS and other than the FP 212-targeted WS. This additional WS is currently coated primarily with 001 resin-based materials and will benefit greatly from the increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments since many of the aircraft of this additional WS operate continuously in maritime environments. Therefore, as a result of this ESTCP project, at least two (and possibly three) DoD WS platforms will benefit greatly, and the economic benefits for DoD should be orders of magnitude higher than those summarized in this report.

## 5.3 OVERALL ANALYSIS OF ESTCP PROJECT WP-0303

The two materials demonstrated and validated during this project, FP 212 and FP 60-2, have lower VOC contents and superior application properties than the materials they will replace. These advantages are expected to result in environmental and economic benefits for the facilities that transition these materials. The durabilities of FP 212 and FP 60-2 in maritime environments were demonstrated to be far superior than the durabilities in maritime environments of the materials that they will replace due to the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments. It is anticipated that transitioning to 002 resin-based materials will allow aircraft that operate continuously in maritime environments to avoid material degradation that would require PDM-level repairs.

The results of this ESTCP project have revolutionized the material stack-ups of two WS platforms of interest, and a third WS is strongly evaluating the results of this project. As a result of this ESTCP project, the material stack-ups have shifted from 001 resin-based materials to 002 resin-based materials, due mainly to the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments. The increased durability of the 002 resin relative to the 001 resin will have far-reaching beneficial impacts to aircraft that operate continuously in maritime environments. Life-cycle VOC and HAP emissions reductions will significantly decrease the life-cycle environmental foot-print of the two WS platforms of interest. The cost reductions to be realized over the life-cycle of the two WS platforms of interest have resulted in financial metrics for this ESTCP project that are highly favorable. Additionally, LM Aero is considering the transition of 002 resin-based materials to replace 001 resin-based materials on a WS platform other than the two targeted during this project. The environmental and economic benefits that DoD should realize as a result of this ESTCP project are expected to be orders of magnitude higher than those reported in this Cost and Performance Report since it was outside the scope of this project to evaluate the benefits of all of the 002 resin-based materials that will be transitioned to the two WS platforms of interest and possibly to a third WS of interest.

# 6.0 IMPLEMENTATION ISSUES

## 6.1 COST OBSERVATIONS

The exceptional durability of FP 212 warranted more testing than was originally planned to attempt to fully assess its failure mode, which caused the cost of this ESTCP program to exceed initial cost estimates. Initially, 8 total blocks of puffer box testing were planned since 8 blocks are required in order to expose materials to a simulated aircraft lifetime of harsh temperatures, pressures and environments. Besides comparing the durabilities of FP 212 and the initial baseline material, it was desired to determine the failure mode of FP 212. Assurance was needed that the failure or degradation of FP 212 would not take the form of large sheets of material that could potentially debond from the substrate during high airflow conditions and that small areas of damage, as is common from debris and battle damage, would not propagate through FP 212. The ideal failure mode would take the form of small, localized areas of degradation that would easily break off in high airflow conditions instead of propagating throughout the material that was damaged. The failure mode of the initial baseline material became apparent during blocks 3 and 4 as severe degradation was observed, but FP 212 showed only one very small crack that appeared in block 8. This small crack did not provide sufficient insight into the failure mode of FP 212, so it was decided by LM Aero, ASC/ENVV, and the SPO of the WS of interest to conduct two additional blocks of puffer box testing in order to try to push FP 212 to failure. FP 212 showed no additional signs of failure during the two additional blocks of testing, and the crack that had formed in block 8 grew only slightly through the ninth and tenth blocks of testing, which provided strong evidence that small areas of damage to FP 212 would not propagate or grow into larger patches of degradation.

In order to provide additional data on the durability and failure mode of FP 212, airflow testing was conducted on FP 212 in subsonic and supersonic airflow conditions. Induced flaws in panels of FP 212 did not propagate but instead broke of britally in small pieces.

The additional blocks of puffer box testing and airflow testing caused minor escalations in the estimated cost for demonstrating FP 212.

In general, aerospace coating vendors provide a tiered pricing scale for coating material purchases. Tiered pricing is a direct reflection of the economies of scale achieved by manufacturing larger product batches. Therefore, a large volume procurement of FP 212 has the potential to reduce the material purchase cost element of FP 212.

## 6.2 PERFORMANCE OBSERVATIONS

The objectives of reducing application time and material usage relative to the baseline material were not achieved. As mentioned in Section 2.1 *Technology Development and Application*, the objectives for this program were based on the performance of FP 212 relative to the baseline material of the WS of interest at the time this ESTCP project began, referred to as the initial baseline material in this report. Results from testing the initial baseline material and FP 212 prior to this ESTCP project indicated that FP 212 would have application time and material usage advantages relative to the initial baseline material. However, mid-way through this ESTCP project, the initial baseline material was replaced with an improved baseline material, which had improved application and material usage properties relative to the initial baseline material.

FP 212 did not have the application and material usage advantages relative to the improved baseline material as it most likely would have had relative to the initial baseline material.

The durability of FP 212 proved to be vastly superior to the durability of the initial and improved baseline materials. The superior durability of FP 212 resulted in additional blocks of puffer box testing having to be performed in an attempt to push FP 212 to the point of failure. Airflow testing, which was not initially part of this program, was conducted on FP 212 to further evaluate its failure mode.

FP 212 has a VOC content that is 90 percent lower than the improved baseline, and decreases in VOC and HAP emissions are expected when the improved baseline material is replaced by FP 212.

## 6.3 SCALE-UP

The transition of FP 212 to full-scale production processes should run smoothly from a procedural standpoint. Transition risk was minimized during this program as FP 212 was designed as a drop-in replacement for the improved baseline material and since FP 212 was evaluated during certain tasks using manual full-scale spray equipment and full-scale structures. No further spray trials will need to be performed at AFP 4, where FP 212 will be applied during production processes with the same full-scale spray equipment that was used during the full-scale application study during this program.

## 6.4 OTHER SIGNIFICANT OBSERVATIONS

Major factors that could present roadblocks to effective implementation of FP 212 have been adequately explored and addressed. Environmentally-advantaged coatings have strong support from the appropriate OEMs, and end user buy-in has already been achieved. Also, reductions in the VOC content of FP 212 have been demonstrated. Therefore, environmental compliance is not expected to hinder technology implementation in any way.

## 6.5 LESSONS LEARNED

Other programs interested in implementing FP 212 will benefit greatly from the full-scale application study data generated during this program. This data will provide application guidance in terms of maximum build rate, ideal time between passes, cure time, and how environmental conditions can affect application properties.

## 6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER ISSUES

The prime contractor for the WS of interest, LM Aero, had significant involvement in this program. The airflow testing, puffer box testing, and full-scale application study were performed by LM Aero at AFP 4, Ft. Worth, TX. In attendance at the Technical Interchange Meetings (TIMs) for this program were the relevant LM Aero engineers, as well as relevant SPO engineers for the WS of interest. LM Aero submitted all raw data from all tests performed on FP 212 to SAIC for preparation of the technical and ESTCP reports. LM Aero also provided data to SAIC concerning how AFP 4 would be impacted if the improved baseline material were replaced by FP 212.

After all testing performed under this program was completed, WS SPO personnel at WPAFB, OH and Ogden Air Logistics Center (OO-ALC), Hill AFB, UT were informed of the program status and of the benefits of FP 212 relative to the baseline materials. SPO personnel located at WPAFB, OH requested a summary package of FP 212 data. LM Aero assembled and submitted the requested information to the SPO personnel, who reviewed the data and authorized the transition of FP 212 to production processes. Additionally, a TIM was held at Hill AFB to brief additional SPO personnel of the WS of interest. During the TIM, all FP 212 test data was discussed, and the benefits of FP 212 relative to the improved baseline material were summarized. Based on the data presented during the TIM, the SPO personnel agreed to begin changing the relevant documents in order for FP 212 to be transitioned to depot processes at Hill AFB for the WS of interest. However, it is not anticipated that there will be much use of FP 212 at Hill AFB. The extent of use of FP 212 at Hill AFB will be to make small area repairs of damaged coating. Since the majority of aircraft of the WS of interest operate in non-maritime environments, and since there is no data to suggest that the improved baseline material has poor durability in non-maritime environments, the only repairs expected for the WS of interest are those from normal flight operations, such as hail and bird strikes, and battle damage. The expected number of these types of small area repairs that will need to be completed for aircraft of the WS of interest are not expected to be significant. The majority of FP 212 usage is expected to be during production processes at AFP 4. WS SPO personnel at Hill AFB were involved in applying the 150 g/L VOC and 40 g/L VOC versions of FP 212 to two aircraft of the WS of interest at Hill AFP. These two aircraft were then deployed to an operational base and provided the 18-month FSE of FP 212. As noted in Section 2.2 *Process Description*, the FSE was conducted under a separate Air Force program that was conducted parallel to this ESTCP-funded program.

## 6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

Title V of the Clean Air Act (CAA) was the primary regulatory driver for this project. There was no involvement or interaction with regulators or governmental validation programs beyond that which was part of normal day-to-day operations at AFP 4, Ft. Worth, TX.

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# APPENDIX A POINTS OF CONTACT

| POINT OF CONTACT Name | ORGANIZATION Name Address | Phone/Email | Role in Project |
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